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## THE PYRUVIC ACID METHOD IN DEEP CLINICAL BURNS\*

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THE CRUX OF THE PROBLEM, both systemic and local, in the treatment of the severely burned patient, relates to the wound itself. In the treatment of the local area the objective is closure of the wound at the earliest moment compatible with success and with a minimum mortality rate. In the patient with an extensive deep burn this should be the objective of all treatment, beyond the early stages of impending or actual peripheral vascular failure. This concept we believe to be the compelling one from a practical standpoint.

The systemic consequences of the large deep burn are too well known to require recital, but it is pertinent here to note that beyond the first few days after injury the general condition of the patient is determined in large measure by one particular feature of the local area. The profound disturbances in the chemical sphere characteristic of this type of patient are reflections of the *open* condition of the wound. This is strikingly witnessed by the precipitous general improvement in the seriously burned patient when the wound is promptly closed. Clearly, the ultimate problem of the patient as a whole is most directly soluble on the basis of the local area. The solution is prompt *closure* of the wound.

The achievement of this objective in the patient with extensive deep burns poses formidable difficulties, however. The present report deals with one of these specifically, and indicates, in general, its bearing upon the others.

Split skin grafts including a proper thickness of the important derma are preferred for closure in large deep burns. Early skin grafting is a major penultimate goal, therefore, but it is not synonymous with closure of the wound. The chief cause of delay in the early grafting of these wounds is, in effect, the continued presence of the slough. This layer of dead tissue is slow

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to separate and is essentially powerless to combat infection; with it skin grafting is impossible, and contraction continues as long as the wound is open. It is regarded as of signal importance, therefore, to bring about the removal of the slough at the earliest moment. The advantage of this rapid removal is fully realized, however, only when the new surface of the wound is acceptable for immediate skin grafting, and when there is no significant damage to living tissue.

In a previous paper (Connor and Harvey,<sup>1</sup> 1944) we presented a brief summary of a method for the local treatment of deep burns based upon the results of experiments in animals. The central theme of the present report deals with the same method adapted for use in man, and the evidence is based upon clinical data.

Fundamental in these studies is the thesis that the hydrogen ion concentration is an important factor in the healing of the local area in deep burns. The results of preliminary experiments revealed that the separation of the slough can be exceedingly hastened if the pH on the surface of the wound is sufficiently lowered, with proper attention to other chemical factors. A large series of organic and inorganic acids were studied for their pertinent effect. Pyruvic acid was found to exhibit outstanding advantages within the recognized objectives of treatment.

#### METHOD

The following data are descriptive of a general method for the use of pyruvic acid in the local treatment of clinical deep burns.

The stock solution of pyruvic acid is made by adding 7 cc. of pyruvic acid C.P. to one liter of distilled water. The pH of the resulting solution should be 1.9.

A content of from eight to ten per cent of cornstarch is desirable in the pyruvic acid starch paste. The exact amount of starch necessary varies somewhat with different commercial brands, but in final consistency the paste should be only semiliquid, permitting easy application. The preparation of the paste is the same whether a large or a small amount is made at one time. The desired volume of stock solution of pyruvic acid is separated into two portions, one (A) of about 20 per cent of the total volume and the other (B) of the remaining solution. Portion (A) is mixed without heating with a calculated amount of cornstarch (8-10 per cent), and thin cold starch paste obtained. Portion (B) is heated to just short of boiling. Portion (B) is then mixed with (A), the cold starch paste, and stirred. With total volumes greater than 400 cc. additional heating with constant stirring for about one minute may be necessary, in order to produce an homogeneous, relatively thick paste. This is then cooled by placing its container in an ice bath. The paste thickens somewhat with cooling.

(Example: If 500 cc. of stock solution of pyruvic acid at pH 1.9 is used, about 100 cc. of this is mixed with 50 grams of cornstarch, without heating. The remaining 400 cc. is heated almost to boiling, and the two portions are mixed, stirred, heated a little longer if necessary, and cooled.)

In the use of this method in the treatment of mixed burns certain general points are of great importance and deserve emphasis.

(1) The success of the method depends to a considerable degree upon the *maintenance* of a *thick* layer of active pyruvic acid paste in contact with the wound.

A relatively *large amount* of paste should be applied, to minimize neutralization by the wound fluids. The paste should be applied generously in a thick layer. This is

## PYRUVIC ACID IN BURNS

most readily done by placing the paste on a thin layer of gauze or on a sheet of appropriate size, which is then applied with the paste next to the burn. After application this inner dressing is covered with strips of vaselined gauze or some impermeable dressing so that it does not dry out. For example, in the treatment of a burn involving the entire lower leg, from knee to ankle, about 3,000 cc. of paste is advisable. An excess amount of paste can be used with safety, an inadequate amount is relatively ineffective.

The dressing should be such as to maintain this thick layer of paste in contact with the wound, and to prevent any conspicuous drying out of the paste. Under a properly applied dressing the paste should not dry out between dressings.

(2) Preliminary cleansing or débridement of the wound is unnecessary. In this connection two points deserve notation, the treatment of blisters and the cross-hatching of the slough, but neither of these can be properly classified as "débridement."

(3) Blisters may or may not be opened. In any instance in which the presence of the slough beneath the blister is suspected, and this occasionally occurs, the blister should be unroofed to expose the dead tissue. If this is not done, the treatment will be ineffective in this area.

(4) Separation of the slough by this method proceeds from the margin of the wound. It is therefore highly advisable in large wounds to incise the slough with a scalpel in order to create more "margins." This can be done without anesthesia. The incisions should be carried through the dead tissue in a linear manner.

(5) Areas of first-, second- and third-degree damage can be treated under the same dressing without conversion of the superficial into deep burns.

*First Dressing.*—The first dressing with the pyruvic acid paste may be performed at any time. In the severely burned patient, in danger of death from peripheral vascular failure, it would appear wise to delay this definitive treatment of the wound in favor of those measures useful in combating the so-called "shock." But the pyruvic acid dressing may be properly applied at once otherwise. In instances in which the local external plasma leakage is excessive, the first dressing may be relatively ineffectual from the point of view of separation of the slough, but this obtains only for a day or two.

Without preliminary cleansing or débridement the dead tissue is incised to provide greater margins, blisters are unroofed if necessary, and the pyruvic acid paste is applied generously in a thick layer directly to the wound. Paste of the proper consistency can be piled in place in many instances. The paste is covered with a thin retaining dressing of dry gauze, which, in turn, is thoroughly covered with large sheets of vaselined gauze or other impermeable dressing to prevent drying. The vaselined gauze has the advantage that, when spread out to include a portion of the adjacent unburned tissues, it helps to anchor the dressing in place and to seal off these edges of the dressing. This is an important feature of the dressing, for properly performed, it is completely adequate to prevent drying out of the paste. This dressing is then covered with a bulky gauze roll and anchored with elastic bandage for security. Splints are incorporated in the outer dressing if necessary, but the best insurance against deforming contractures is early closure of the wound with proper skin grafts.

The application of dressings of pyruvic acid paste to large burned areas on the extremities can be simplified by placing the burned area on a sterile towel, and applying the paste generously to the wound and on the towel; the paste-filled towel is then drawn around the extremity, anchored and sealed with large sheets of vaselined gauze. Such a method insures the covering of the wound with a thick layer of paste, and over it the outer dressing is easily and efficiently applied.

For the treatment of burned areas on the flat surfaces of the body, as the dorsum of the hand and the trunk, the paste is easily held in place within a dam of built-up gauze applied to the greased unburned skin at the margins of the wound. Within this dam of gauze the paste is placed in a thick layer, covered with dry gauze and sealed

with sheets of vaselined gauze. Such a dressing maintains the pyruvic acid in place without drying for several days.

Whenever possible in instances of burns of the extremities, the unburned distal portion of the extremity should be left exposed for inspection. A few preliminary vertical incisions through the slough are good insurance against compromise of the circulation locally from the tourniquet effect of the unyielding eschar.

*Pain* is irregular in occurrence after these dressings. It is reasonable to expect pain after the application of pyruvic acid directly on a denuded second-degree area, but this has not been invariably the case. The intensity and duration of the pain, when present, are also variable. Although several large burned areas of mixed degree have been successfully treated by this method without apparent pain, it would seem wise to administer codeine or morphine about 15 minutes before at least the first dressing. Various methods have been used for the incorporation of a local anesthetic agent into the pyruvic acid paste, but these have not been refined sufficiently to make them safe in the presence of large wounds.

*Subsequent Dressings.*—The pH of the pyruvic acid paste rises in the presence of the wound fluid, particularly when the external plasma leak is excessive (the first few days after burning) and when the slough has begun to separate. Dressings should be performed at intervals of two to three days, if possible.

When the previously placed dressing is removed the paste should not have dried out, and the entire inner dressing should fall away from the wound without pain. A thin layer of paste usually remains on the surface of the wound; this should be wiped away gently.

The conspicuous change at the first redressing is the *demarcation* of the areas of dead tissue, and this occurs whether the burn extends only into the depths of the derma or into the deeper layers. In fresh burns there may be little gross evidence of separation at this time; in older burns the edges of the slough may show obvious separation.

Whether or not *débridement* is combined with the use of pyruvic acid at redressings (see below for discussion) the new dressing is applied in a manner entirely similar to that used in the previous one, a generous application of paste being used.

At the second redressing in large third-degree burns beginning separation of the slough should be apparent. It is at this time that *débridement* according to a particular technic is of great value, for the demarcation of the slough in both the vertical and horizontal planes will be obvious.

In third-degree burns not involving tendons or thick fascia the wound should be ready for split grafting within a week or slightly longer. The new base of the wound should consist of well-vascularized early granulation tissue. If grafting must be delayed momentarily, the wound may be dressed with a small amount of the pyruvic acid paste.

*Deep Second-degree Burns.*—Areas in which the damage extends only into the depths of the derma, with preservation of deep epidermal islands but with a covering of slough, should receive the same treatment as deeper areas. When the cleavage plane is within the derma, an additional 48 hours may be required for complete separation of the dead tissue. When such separation has taken place, however, the wound should heal promptly, if sufficient epidermal islands are present. In such instances healing is often surprisingly rapid when the slough is speedily removed without clinical infection, even though the layer of dead tissue is relatively thick.

*"Débridement."*—The early demarcation of the slough and consequent definition of the proper cleavage plane with this treatment permits a valuable modification of the method. This consists in the use of "*débridement*" together with pyruvic acid at the time of the redressings. The term "*débridement*" is employed rather loosely in this connection since the maneuver is used merely to hasten, but not to complete at one sitting, the separation of the slough.

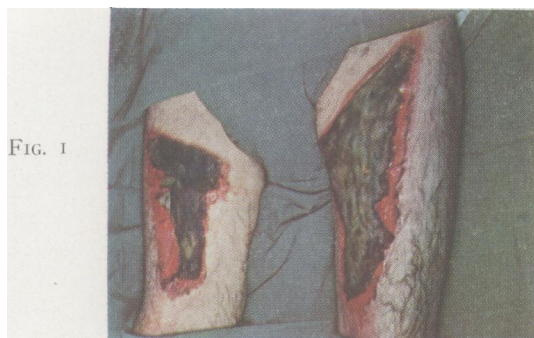


FIG. 1

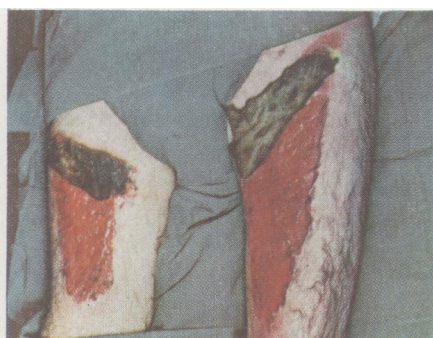


FIG. 2



FIG. 3



FIG. 4

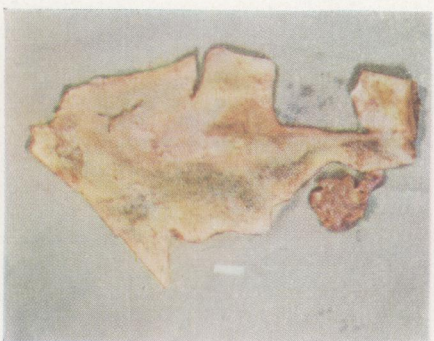


FIG. 5

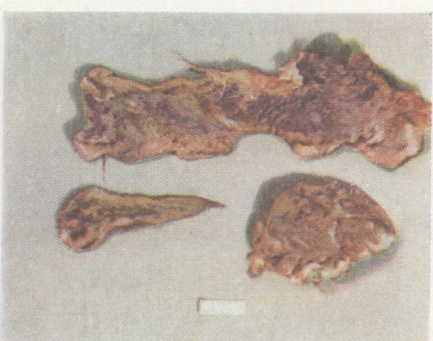


FIG. 6

# PLATE I

FIGS. 1 and 2.—Case 1. A. C.: Separation of the slough in one piece through the development of a cleavage plane beneath it (see text).

FIGS. 3-6.—Case 2. J. K.: Severe electrical burn of arm and leg, to show rapid separation of the slough and clean granulating wound (see text).

Although separation of the slough proceeds with the use of the pyruvic acid paste alone, the process can be materially hastened with safety when the demarcated plane of cleavage is developed by sharp dissection for a few centimeters beyond the established limits of complete separation. This is true *even though the cleavage plane is within the derma*, and sufficient residual epidermal elements are present. The safety of this maneuver is dependent upon the fact that the proper plane of cleavage is sufficiently defined by demarcation of the slough to be obvious grossly, and that a zone of incomplete separation often lies among the areas of complete separation. For example, in a large deep burn at the end of four days of treatment the slough may have separated at the edges so that elevation of these margins reveals only vertical strands of dead connective tissue anchoring the slough to its base, with many large and small intervening areas of complete separation. When these anchoring strands of slough are divided, bleeding is absent and the cleavage plane is further developed, so that the subsequent application of pyruvic acid reaches the more remote areas under the residual slough. This extension of the line of cleavage, surgically, should properly extend inward only to the point where demarcation is entirely clear, if the destruction of residual epidermal elements and bleeding are to be avoided.

*Stronger Stock Solution.*—When there is no question of preservation of residual epidermal islands, the strength of the stock solution may be increased to 9 cc. of pyruvic acid per liter of distilled water, until the slough has separated.

When the slough includes dense tissue or tendons, separation is considerably hastened when débridement by the above technic is employed in addition to pyruvic acid.

#### RESULTS

More than 30 cases have been treated in this manner, many of them with multiple wounds. The results have been similar to those previously described in the experiments in animals. The layer of dead tissue separates rapidly, and living islands of skin survive in those areas in which the full-thickness of the skin has not been destroyed in the burning. The deep wounds are then acceptable for immediate grafting, and in the more superficial wounds the islands of viable epidermis regenerate. All areas of the mixed clinical burn may thus be treated under the same dressing.

The manner of separation of the slough under these circumstances is of great significance. This is strikingly apparent in the experimental wound and is equally clear in the clinical cases. Separation appears to begin at the margin of the slough and to proceed centrally through the development of a plane of cleavage beneath the dead tissue. The slough separates in large sheets. It is clearly apparent that the slough itself is not digested. This is well-illustrated in the following case, and in Case 4:

CASE 1.—A. C., a white male, age 50, sustained deep burns of the thighs in attempted suicide, and was admitted to the hospital in critical condition from carbon monoxide poisoning. The wounds were treated with vaselined gauze and pressure dressings. After 20 days the slough had failed to separate and was firmly adherent in all areas, even at the margins. A dressing of pyruvic acid was first applied at this time. The proximal few centimeters of the wound on each thigh was left *untreated*, except for a minimal amount of paste which leaked onto this area. The remainder of the wound was completely covered with a thick layer of paste.

The dressing was changed three days later. The slough had separated markedly in many peripheral areas but was firmly attached proximally. Pyruvic acid paste was again applied in a thick layer.

*Six days after the initial treatment* by this method the slough had completely separated except for a thin proximal band (Fig. 1). The slough lay on the surface of the wound and could be lifted free, hinged proximally (Fig. 2). The separated layer of dead tissue itself was rubbery and intact in a single sheet on each wound. The granulating surface of the wound was clean and highly vascular, but there was no bleeding from it. At the margins of the wound there were several areas of viable deep derma. The surrounding skin was uninjured.

The granulating wound was successfully closed with split grafts. In the areas of exposed deep derma at the margin epidermal islands promptly regenerated, but in the remainder of the wound the damage was of third-degree.

This case illustrates particularly well the separation of the slough through the development of a cleavage plane beneath it. The slough itself was not digested. With this treatment it is clear that separation begins at the margin. In this case the margins of the wounds were relatively large compared to the area of the slough, and the slough was purposely not incised to create more margins. In circumferential deep burns of the extremities the margins of the wound may be exceedingly small (Case 4); under these circumstances there is a great advantage in a few linear incisions through the dead tissue in order to provide a relatively large "margin."

Preparation of the local area in the large deep burn for grafting within a period of even a month is often regarded as efficient treatment in clinical practice. With proper application of the pyruvic acid method the usual large deep thermal burn should be ready for successful grafting within a period of ten or 12 days, often in less time. Smaller burned areas should be prepared within a proportionately shorter period, approaching that previously noted in the experimental deep burn.

The surface of the wound is exceptionally vascular after separation of the slough by this method, but there is no bleeding. When the treatment is begun at an early date, and is intensive, this new surface of the wound may have the general appearance of pink subcutaneous tissue; histologically, it is early granulation tissue. The edges of the wound are sharp and clean.

Severe electrical burns are commonly regarded as particularly destructive and troublesome. They would appear to be an adequate testing ground for the efficiency of a method of local treatment. Many of the features of the present method are shown in the following case:

CASE 2.—J. K., a white male, age 51, sustained severe electrical burns of the arm and legs from prolonged contact with a high tension wire. The wounds were treated initially in another hospital with a thin dressing of sulfonamide cream. This, and a dressing of vaselined gauze, were the only local treatment for two days.

*Two days after burning*, and before the first dressing with pyruvic acid paste, the local areas revealed evidence of marked destruction (Figs. 3 and 4).

The soft tissues of the arm (Fig. 3) were completely divided down to, and exposing, the humerus just above the elbow. A wrist drop was present. This arm had supposedly hung sputtering over the high tension wire. When the divided muscles which filled this groove were separated, a charred mark about 2 cm. in diameter was viable in the humerus itself, and this bone was bare over two-thirds of its circumference for a distance of about 5 cm. The adjacent tissues upward and downward from this groove were the site of a rubbery, insensitive slough which was firmly

FIG. 7



FIG. 8

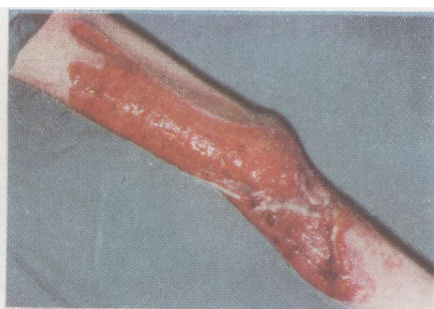


FIG. 9



FIG. 10



FIG. 11



FIG. 12



## PLATE II

FIGS. 7-9.—Case 2. J. K.: Severe electrical burn of arm and leg, to show rapid separation of the slough and clean granulating wound (see text).

FIGS. 10-12.—Case 3. E. E.: Deep second-degree burn, to show prompt separation of slough with preservation of viable epidermal islands (see text).

adherent. A large patch of gray similar tissue extended medially across the antecubital space.

A similarly destructive injury was present over the left thigh, popliteal space and lower leg (Fig. 4). Here, again, the soft tissues had been divided in the burning down through the muscle. The tibia was exposed just below the knee for a distance of about 2 cm. The remainder of the burned area was covered with a layer of rubbery gray tissue which was firmly adherent. A drop foot was present.

On the opposite thigh (right) was a smaller area of damage without actual division of tissue. This was covered also with a layer of adherent, insensitive slough.

In view of the nature of the burning agent (electricity) and the actual division of tissue under these circumstances it was suspected that the damage was even more extensive than it appeared to be.

The pyruvic acid treatment was started at this time, two days after burning. Edema had become marked in the unburned tissues distal to the burn. A linear incision was made in the unyielding slough over the arm and over the popliteal space without anesthesia. All of the wounds were treated simultaneously, and a thick layer of pyruvic acid paste was applied.

The dressings were changed at the usual intervals of a few days. Large areas of slough promptly separated in sheets, some of which are shown in Figures 5 and 6. The slough of skin and subcutaneous tissue which came away from the knee and thigh was more than 0.5 cm. in thickness in several areas (Fig. 5). In addition, sections of muscle at least 6 cm. in thickness (Fig. 6) separated in one piece from the walls of the original grooves in the arm and leg. The slough itself was not digested, and separation had taken place through the development of a cleavage plane beneath it.

*Thirteen days after the first pyruvic acid dressing* all of the wounds were free of slough and in excellent condition (Figs. 7, 8 and 9). The vascularity of the exposed tissues characteristic of this treatment was marked, but there was no bleeding from them. In the right arm (Fig. 7) the humerus was exposed for several centimeters. The bone here appeared a dead grayish-white in color and presented the previously noted blackened area in it. The edges of the wound were sharp and clean. In the left leg (Figs. 8 and 9) the wound was essentially similar to that in the arm. Tendon and fascia were exposed around the knee, but these tissues appeared to be viable. The tibia was exposed as already noted.

The soft tissue wounds were covered with thick split grafts which survived for closure of the defect in these tissues.

The utility of this method of treatment would be seriously reduced if with its use residual epidermal islands within the wound were necessarily destroyed. This is not the case, however, for in those burns in which the serious damage extends only into the derma, but with preservation of residual epidermal islands, separation of the slough proceeds so as to permit regeneration of these islands. The cleavage plane develops within the derma at the appropriate depth.

This emphasizes an important feature of the method. In the standardization of the procedure for practical application the concentration of pyruvic acid was chosen with this consideration. When there is no need for preservation of these deep epidermal islands a stronger solution of pyruvic acid may be used, with even more rapid separation of the slough. The usual clinical deep burn is a mixed one, however, with at least small areas of more superficial damage. In repeated instances in the present series of cases numerous viable epidermal islands have been present after separation of a thick slough

by this method. The method was standardized with a view to the preservation of these deeper epidermal islands. All areas of the mixed clinical burn may thus be treated under the same dressing without fear of converting the superficial injury into a deep one.

A conspicuous feature of this method is the early *demarcation* of the slough in questionable areas. In fresh burns it is often difficult to determine with accuracy in the beginning the extent of the layer of dead tissue.

The following case illustrates the separation of the slough in a wound in which deep epidermal islands were viable. Although the area in question is small, this case was chosen as particularly suited to illustrate the point. The small local area was intensively treated from the beginning, and when the slough had separated, the exposed surface of deep derma was further treated with the same pyruvic acid paste. This additional treatment is not recommended, as other agents are better adapted for use once the local problem involves only epithelization from islands within the wound.

CASE 3.—E. E., a white female, age 26, sustained a burn of the upper and lower arm when her sweater caught on fire. The burning was of short duration. She came to the hospital within a half hour after injury.

The entire arm was burned. Most of the local area appeared to be only superficially injured, however, with many intact and collapsed blisters. There was one grayish area on the inner aspect of the upper arm near the elbow (Fig. 10), suggesting somewhat deeper damage.

The entire burned area on the arm was dressed with a thick layer of pyruvic acid paste. The patient reported (on questioning) a slight local twinging sensation for about five minutes, but refused medication.

*Two days later* there was conspicuous demarcation of the slough on the grayish area previously noted (Fig. 11), but there was no gross evidence of separation. The adjacent blistered area appeared undamaged. Pyruvic acid paste was again applied, and medication for pain was not required.

*Three days later* the slough had markedly loosened but had not completely separated. When its edge was lifted, however, it was apparent that only a few soft dermal strands held it in place. The layer of dead tissue was peeled away at this time, like wet paper from glass. There was a slight hang at only one point near the center. The separated slough was intact (Fig. 12) and showed no evidence of digestion. The surface of the wound exposed after separation of the slough appeared to contain deep dermal tissue (Fig. 13) and was clinically clean.

This wound, free of slough, was treated for an additional five days with a thin layer of pyruvic acid paste. Numerous epidermal islands in the base of the wound regenerated in spite of this treatment, and the entire wound was completely epithelized one week later. The patient failed to return for photography but was finally induced to do so, one month after burning (Fig. 14).

The impression that superficial burns (without a significant covering of dead tissue) form an adequate testing ground for the efficiency of method for the local treatment of burns in general is a mistaken one, and has led to waves of enthusiasm for procedures which fail to prove their advantage in the presence of slough. We wish to note, therefore, that Case 3 has been cited only for the specific purpose of illustrating the safety of the pyruvic acid method in this type of injury.



FIG. 13



FIG. 14



FIG. 15

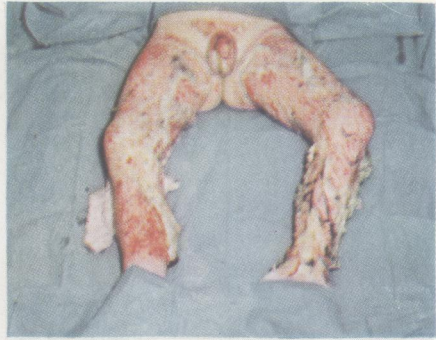


FIG. 16



FIG. 17



FIG. 18

### PLATE III

FIGS. 13 and 14.—Case 3. E. E.: Deep second degree burn, to show prompt separation of slough with preservation of viable epidermal islands (see text).

FIGS. 15-18.—Case 4. J. V.: Severe deep burn by fire, to show rapid separation of slough in sheets, clean granulating wound acceptable for prompt closure with split grafts, immediate and late results of grafting (see text).

The full advantage of the rapid removal of the slough is realized only when the wound is acceptable for immediate skin grafting and is promptly closed, even though it is extensive. When the entire large deep burn is rapidly prepared for grafting, the gain is only a relative one unless the open wound is promptly converted into an essentially closed one. As has already been noted, this concept we believe to be the cogent one from a practical standpoint.

The clean vascular surface exposed in deep burns after separation of the slough by this method is admirably suited to support a covering of living skin, regardless of the presence of bacteria as indicated by culture. This is true even in the deep burn which is clinically infected when the pyruvic acid treatment is begun (see Case W. T., Connor and Harvey,<sup>1</sup> 1944). It is probable that few bacteria multiply and that many will not survive at the concentration of hydrogen ions present in the pyruvic acid paste. The more important factor in the survival of the skin grafts is believed to be the highly vascular clean surface of the wound, since bacteria are regularly obtained upon culture of this area.

It is understood that the rapid closure of the extensive deep burn free of slough poses serious difficulties. The various ramifications of this aspect of the problem are widespread, but it is pertinent to note here that the pyruvic acid method attains real significance in direct proportion to the speed with which the prepared open wound is converted into an essentially closed one.

The following case illustrates the relationship of the pyruvic acid method to the general problem in severe deep burns:

CASE 4.—J. V., a white child, age eight, was admitted to the hospital a half hour after having sustained a severe burn of both entire lower legs when his clothes caught on fire. There was some delay in extinguishing the fire since he had oil on his trousers. His left stocking was rolled down around the ankle and was also oil-soaked.

At the time of admission to the hospital both lower extremities were circumferentially burned. A linear incision was made in the unyielding charred skin to avoid constriction. A conspicuous ring of gray tissue was present around the left ankle at the level of the malleoli, this being notable in view of later developments. The greater part of both lower extremities appeared seriously damaged.

Intensive measures to combat peripheral vascular failure were instituted, and a pressure dressing was applied over vaselined gauze without preliminary cleansing.

*Three days later* the patient's general condition was satisfactory and the first dressing of pyruvic acid was applied, 6,600 cc. of paste being used for both lower extremities. The burned areas were little changed (Fig. 15) and were incised with a scalpel, linear and transverse incisions several centimeters apart being made to create more margins before the dressing was applied. The wound was not cleansed or débrided.

*Two days later* the slough had begun to separate. A dressing of pyruvic acid paste was again applied to both lower extremities.

*Three days later* (eight days after admission, five days after first dressing with pyruvic acid paste) much of the slough was hanging loose or had completely separated in a large sheet, and most of the remainder of the slough was held in place only by soft strands (Fig. 16). It was clear that a cleavage plane had developed beneath the slough which was still in place, and that the separated slough was without evidence

of digestion on its surface. The separated slough, which hung loose in sheets, was cut free from the incompletely separated dead tissue. Pyruvic acid paste was again applied.

*Two days later* (ten days after admission, seven days after the initial pyruvic acid dressing) the wound was free of slough and acceptable for grafting. The patient developed serum sickness (tetanus antitoxin administered on admission) which lasted for only a few days. There was considerable difficulty in securing compatible blood donors, the patient being *Rh-negative*. Extensive grafting was planned for the first operation, and intensive efforts were made to bring the patient's general condition to a high level to permit this. An exceptionally high protein diet was administered and the daily urinary output was maintained at about 2,000 cc.

*Five days later* (12 days after initial pyruvic acid dressing) sufficient compatible *Rh-negative* blood was available, and the wounds were in excellent condition. There were several striking features of the burned areas at this time. The surface of the wound was clean and highly vascular without bleeding (Fig. 17). The deepest damage was at the ankle on the left side. Both malleoli were exposed over an area of more than a centimeter in diameter, the joint space was widely open medially and laterally; the Achilles tendon, the peroneal and extensor tendons at the ankle were also exposed. These tendons appeared to be in good condition otherwise.

On this day the wound was extensively covered with split grafts, these being secured from both buttocks, the lower back on each side, both shoulders, both sides of the anterior abdominal wall and the anterior chest. About 200 square inches of skin was grafted at this one operation. Donors for homografts had been kept in readiness but were not used since the patient withstood this extensive procedure well. The granulating areas over the knees and popliteal spaces, and the exposed tendons were covered first, since these were of the greatest importance from a functional standpoint; the exposed tendons were grafted directly. All the available skin grafts were used without accurate patching, since skin was at a premium for complete coverage of the large granulating areas.

The grafts took well in all areas, including those over the Achilles tendon and extensor tendons. Intensive general treatment was continued to permit successive operations for closure of the wound as soon as possible.

*Seven days after the original skin grafting*, additional split grafts were taken from the skin in the axillae and over the lateral aspect of the chest and buttock on each side as well as from part of one of the *previous donor sites*, permitting further closure of the wound. Again, effort was made to conserve skin and small areas were left between the grafts in some places. The previous grafts had taken around the malleoli which had been exposed, but this bone was now covered with granulation tissue, which was covered with small grafts at this operation. The patient tolerated this procedure well.

*Five days later* (12 days after the first grafting), much of the wound was covered with living split grafts with an adequate dermal pad (Fig. 18). Greatest attention had been given to the knees, and the grafts here were placed close together. Patchy areas of granulation tissue were apparent where the grafts otherwise had been spread for greatest coverage but without too much regard for small areas between them.

In addition to these small areas there remained one large area on the posterior aspect of the upper thigh on each side and one on the lower leg, yet to be grafted. Most of these were covered on this day with sheets of skin obtained from *three of the original donor sites which had now healed*. The original grafts taken from these areas were used to cover the knees and contained about one-half of the derma.

*Thirty days* after the first pyruvic acid dressing (33 days after admission) the wound was essentially closed (Fig. 19). There remained only a few scattered granulating areas in between the grafts which had been placed for greatest coverage without accurate patching. Three small areas were closed with bits of split grafts in order

FIG. 19



FIG. 20



FIG. 21



FIG. 22



#### PLATE IV

FIGS. 19-22.—Case 4. J. V.: Severe deep burn by fire, to show rapid separation of slough in sheets, clean granulating wound acceptable for prompt closure with split grafts, immediate and late results of grafting (see text).

to improve the ultimate functional result, although most of them would probably have epithelized rapidly.

Fifteen months after the original injury the local areas were all in excellent condition (Figs. 20, 21 and 22). There were no contractures, the transplanted skin was durable and freely movable (Fig. 20), especially over the important area of the knees. There was no palpable deep scarring except over the left ankle where, it will be recalled, the joint space had been widely open and many of the supporting ligaments destroyed. This joint had become dislocated and there had developed evidence of a local epiphysitis. The functional result was otherwise excellent.

#### SUMMARY

The results in clinical cases of deep burns treated by the pyruvic acid method support those obtained with similar treatment of experimental burns in animals. The slough separates rapidly without significant damage to living tissue, and the wound is immediately acceptable for extensive skin grafting regardless of the presence of bacteria as indicated by culture. The ultimate objective of treatment in deep burns, namely, the early closure of the wound, can thus be speedily achieved.

The authors wish to express their appreciation to Dr. Philip B. Cowles of the Department of Immunology, Yale University, for his invaluable assistance in this study.

Acknowledgment is due to Miss Mildred Konick for the photography.

#### REFERENCE

- <sup>1</sup> Connor, G. J., and Harvey, S. C.: The Healing of Deep Thermal Burns: A Preliminary Report. *ANNALS OF SURGERY*, 120, 362-366, 1944.

DISCUSSION.—DR. JOHN STAIGE DAVIS, Baltimore, Md.: I had not intended to say anything tonight, but I cannot resist speaking about this last paper. The method has apparently solved the problem of disposing of deep burn sloughs, which is something we have been struggling with for years, and to which we have never previously had a satisfactory answer. The results shown are remarkable, and I think pyruvic acid is going to make a great difference hereafter in the treatment of burns. I congratulate Doctors Harvey and Connor on this splendid piece of work.

DR. OLIVER COPE, Boston, Mass.: All of us who have had the privilege of going to New Haven and seeing some of Doctor Connor's patients have been much impressed by the extraordinary change created by pyruvic acid paste. I have reservations regarding the exact rôle of the  $pH$  of the paste. There are properties other than the  $pH$  which may help along the way. Doctor Connor has not told us all of his tricks; he is adept at making epithelium sprout by changing from pyruvic to succinic acids.

Doctor Lund's paper, and the work his group has been doing has been of enormous interest to other workers in government research projects in this field. Vitamin C is interwoven with the alarm reaction and it and other vitamins may be involved in the reaction of the patient to infection. It has been of great interest and help to us to have seen their work.

In the absence of Doctor Moore, I would like to allude to our work. The methods which Doctor Moore has developed using radioactive isotopes are magnificent tools but, after all, the value of tools is the result and knowledge obtained with them. Doctor Moore has been able to tell us a lot, but we do not pretend to know all the answers regarding the massive red cell destruction in deeply and extensively burned patients.